A WSN Integrated Solution System for Technological Support to the Self-Sufficient Elderly

Paola Pierleoni, Alberto Belli, Lorenzo Palma, Michele Palmieri and Luca Pernini

Abstract The proposed system is basically an automatic dispenser of medicines which integrates functionalities of remote and real-time monitoring of the activities of the elderly in home environment. It includes the generation of alarms resulting from the omission of taking medicines and other critical events such as the permanence of the elderly in a room for a period not consistent with normal daily activities. The main elements of this system are a pair of LED smart lamps called MARCH'ingegno and Sibilla, the first one is the dispenser of medicines which embeds WSN coordinator role, located in the house of the elderly, the other is the displays of real-time alarms, located in the house of relatives or caregiver. The mobility monitoring system is composed of wireless sensor nodes distributed in the house of the elderly. MARCH'ingegno acquires information from these sensors through its RF interface, processes it and transfers the report to a remote web server together with the notes of taking medicines. The tests show that the system operates properly and the wireless sensor nodes ditributed at home provide an adequate coverage area and correct response times.

1 Introduction

This project involves the construction of an intelligent system of remote real-time assistance of elderly people living alone. With this project, Semar s.r.l. won the competition organized by the Marche region [2], "Casa intelligente per una longevitá attiva ed indipendente dell'anziano."

P. Pierleoni · A. Belli · L. Palma · L. Pernini
Information Engineering Department (DII), Universitá Politecnica delle Marche, Via Brecce Bianche 12, 60131 Ancona, Italy
e-mail: p.pierleoni@univpm.it

M. Palmieri (✉)
Semar s.r.l., Via Sardegna 5, 60022 Castelfidardo, Italy
e-mail: Michele.Palmieri@semar.biz

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The main elements of this system are MARCH'ingegno and Sibilla: a pair of LED smart lamps where local and global communication systems and various solutions for Ambient Assisted Living are integrated. MARCH'ingegno, is a low energy lighting and design element. It is equipped with a service of automatic dispenser for the daily dosage of medicines. In addition, it integrates a system for the mobility monitoring of the elderly in the home environment with the generation of alarms resulting from critical events such as the omission of taking medicines or the permanence in a room for a period not consistent with normal daily activities.

The system of the mobility monitoring is realized by wireless presence sensors distributed in the home environment. MARCH'ingegno acquires the information from these sensors, processes data and transfers the report to a remote web server via Internet connection. The system is capable of producing a remote alarm on the mate lamp Sibilla (placed in the house of relatives, guardian, nurse, etc.) in case of critical events. Sibilla can report critical events and provides real-time information on the mobility of the elderly through LED display. The mobility details, the taking of medicines and the related alarms are also available on a web server accessible by authorized users through a PC or Smartphone application.

The strength of the system is its scalability with a number of density of nodes and different kinds of sensing features. Therefore, we can simply extend the variety of applications for the constant care and the safety of the elderly to other applications such as vital sign monitoring, fall detection, dietary/exercise control, etc. Our system benifits from the wireless capability, the collaborative and synergic sensing task, the date processing and the efficient communication that enable reliable unattended operations.

2 Design and Implementation of the System

The goal of the present work is the development of a system of continuous aid elderly people. This section describes the basic elements of the realized system: the sensor nodes, the smart lamps MARCH'ingegno and Sibilla and the web server services.

2.1 Sensor Nodes

The mobility monitoring system consists of indoor distributed sensor nodes. Each node contains a motion sensor that detects the movements in a given coverage area and therefore the presence of the elderly in a specific room. The sensor nodes are equipped with RF, interface which transmits data to a concentrator node (located into MARCH'ingegno) that suitably elaborates the received information.

The sensor nodes are designed to be plug and play installed and non-invasive for everyday life.

2.1.1 Motion Sensor

The motion sensor includes a Passive InfraRed (PIR) sensor and a processing unit suitable for our application. In order to improve performance of PIR sensor a Fresnel's lens is added.

PIR sensor

In order to sense human motion, the PIR sensor should only be tuned to detect radiation from a human that arrives in its proximity. However, the sensing elements are responsive to radiation over a wide range. Therefore, a filter is used to limit incoming radiation in the 8–14 μm range, according to the human body radiation.

Thus, the IR rays, after passing through the filter, strike the sensing element that generates a charge. The magnitude of the charge produced is directly proportional to the amount of rays that strike on the sensing element. The charge produced by sensing element manages to generate voltages that control a Field Effect Transistor (FET) following by an impedance converter. Thus, the FET modulates the output of the PIR and transmits the output signal to a processor unit.

In this project a RE200B-P PIR sensor [3] is used. It is designed to pick up heat radiation of wavelengths in a band of about 10 μm. It contains two sensing elements connected in a voltage bucking configuration. Thanks to this configuration we can have a good compensation of environmental temperature, excellent sensitivity for small changes and reduction of signals caused by vibration and sunlight.

The output signal of the PIR generates voltage changes on the order of μV which are difficult to process, this output is amplified and suitably elaborated by a processing unit.

Processing unit

A motion sensor can be realized by just connecting the output of PIR to a processing unit. As shown in Fig. 1 the realized processing unit can be divided into three elementary blocks: amplifier, comparator and signal processing. The output of PIR sensor feeds into a two stage amplifier having signal conditioning circuits and a high gain. The amplifier is bandwidth limited to about 10 Hz to reject high frequency noise and is followed by a window comparator that responds to both the positive and negative transitions of the amplifier sensor output signal. The output of the comparator produces a 0 to Vcc transition on the signal based on the amount of IR rays that strike the surface of the PIR sensor. This signal is sent to the signal processing block which provides a digital output indicating the presence (high level) or absence of motion (low level). Thus, the movements can be detected by checking for a high signal on a single digital pin of this motion sensor.

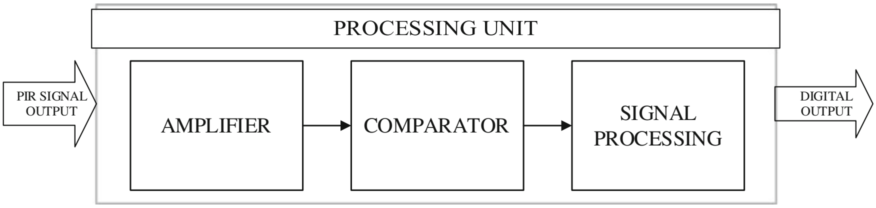

Fig. 1 Block diagram of the motion sensor processing unit

The reliability of this kind of sensor can vary with environmental conditions. The processing unit is designed to slowly adjust at the changing conditions in the environment that normally take place during the day. The motion sensor has a specific coverage area in which a moving person can be detected. The sensor coverage area varies based on of the size of the monitored environment, for this reason, the motion sensor sensitivity must be adjusted according to the distance range and visibility angle range of the sensing region.

Fresnel lens

In order to increase the coverage area of motion sensor it is necessary to focus the infrared radiation on the surface of the PIR sensor. This is accomplished using a plastic chamber called Fresnel lens. It consists of an array of curved segments that capture more infrared radiation and focus it to a relatively smaller point. In fact, the lens is designed to have its groove toward the sensing elements of PIR sensor.

The placement of the sensor beneath the Fresnel lens is crucial as it supposed to receive maximum amount of infrared radiation that comes from the lens array.

In order to focus the infrared radiation on the surface of the realized motion sensor a NL-11NH Fresnel lens [4] is added. This lens is positioned at a distance of 1.29 inches from the sensing element of PIR to direct maximum amount of infrared radiation on it.

2.1.2 RF Interface

After detecting the presence of a person in a room, each sensor node transmits data through its embedded RF interface to a concentrator located in MARCH'ingegno that processes the received information.

In this project, the XBee ZB RF Module [1] is used as RF interface. It contains a transceiver operating on frequencies of 2.4 Mhz with a power that varies depending on the models from 1 mW up to about 60 mW, an antenna or a connector for external antennas and an integrated microcontroller. Communication protocols that provide wireless connectivity to other several modules are implemented in the embedded microcontroller to create a ZigBee mesh networks. The XBee ZB RF modules are designed for high-throughput applications requiring low latency and predictable communication timing. It operates at data rate of 250 Kbps with an indoor range coverage up to 40 m. In the XBee ZB modules there is also the possibility to monitor the logic level of digital pins that are provided in their RF interfaces. The logic level of specific digital pin can be read locally and then transmitted to a remote XBee ZB RF Module.

Our system, MARCH'ingegno is equipped with XBee ZB RF Module because it has the function of network coordinator. It is the core of the Zigbee network and keeps the security keys and the network information. Thus, the RF interface of MARCH'ingegno is programmed to automatically create the mesh network and permits association of the other XBee ZB RF nodes to the WPAN.

Each other sensor node has a ZB RF Module which is configured for connection to the mesh network created by MARCH'ingegno: as soon as a sensor node authenticates itself it can transmit data within the network. Each sensor node is authenticated with the identifier of the room where it is placed. The XBee ZB RF Module is configured to immediately transmit to the coordinator a data whenever a specified digital pin changes state. The output of the motion sensor is attached to this specific digital pin.

2.1.3 Performance of Sensor Nodes

The proposed detection system was experimented in an indoor testing environment in order to evaluate its performance. The results of the tests show that each motion sensor requires a calibration time to properly function. This calibration time varies from 10 up to 60 s according to the environment in which it operates. After the calibration time, any thermal signal far below to one μW is sufficient to trigger a voltage change on the output amplifier of the motion sensor. In order to evaluate the coverage area, several tests were conducted to measure the sensor distance range and visibility angle range changing the sensitivity of the device. These tests were also carried out with the sensor without lens to evaluate the decrease in performance. The results of tests carried out with the addition of the Fresnel lens show a considerable increase of the coverage area of motion detection. Indeed, as shown in Table 1, the detection is more stable and the visibility angle range is also increased about 30° with a Fresnel lens.

As illustrated in Fig. 2, the results also show that, at the maximum sensitivity, the coverage area of the motion sensor has a range of about 6 m. So follows that the sensor node provides an adequate coverage area to monitor an entire room.

2.2 The Smart Lamps MARCH'ingegno and Sibilla

The ZigBee module placed into MARCH'ingegno receives the data sent from sensor nodes distributed in the house. In order to determine the permanence of the

Table 1 Visibility angle range of motion sensor

Sensitivity (%)	Visibility angle range with lens (Degree)	Visibility angle range without lens (Degree)
0	90	60
25	105	90
50	120	105
75	150	120
100	180	150

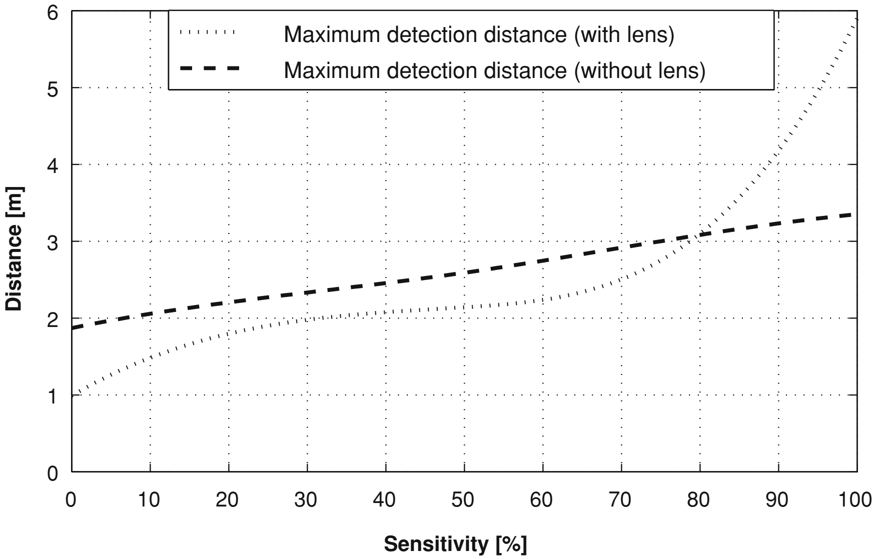

Fig. 2 Distance range of motion sensor changing the sensitivity

elderly in a specific room, the information sent from each sensor is processed by an embedded microprocessor into the smart lamp. An algorithm implemented on this microprocessor determines the residence time of the elderly in each room. Finally, these periods are compared with a specific threshold of danger to generate alarms in case of exceeding this time limit.

The danger thresholds corresponding to the specific room are obtained on the basis of a statistical survey that we have carried out. This study was conducted on a sample of 100 subjects (43 males and 57 females), aged between 70 and 87 years. The results of the study are shown in Table 2 where there is a subdivision in four typical rooms and four periods of the day.

The data resulting from this study are used as default parameters for the generation of alarms but are also remotely editable via a web server that allows to calibrate the system based on the behavior of each user.

Table 2 Percentage of time in which the subjects examined remain in every room of the house, for every time band

Time of the day	Kitchen (%)	Livingroom (%)	Bedroom (%)	Bathroom (%)
Morning (7–13)	27	39	24	10
Afternoon (13–19)	20	55	20	5
Evening (19–23)	20	50	23	7
Night (23–7)	1	4	92	3

The dispenser of medicines can be monitored through the remote web server. In fact, MARCH'ingegno is primarily an automatic daily medicine dispenser. Has several drawers that can contain a variety of different medicines. The microprocessor of MARCH'ingegno can be programmed to open the drawer at fixed daily times and contemporary to emit light signals and sound effects to remind the elderly to take the medicines. The service dispenser of medicines can be configured locally or remotely and the settings be modified whenever changing the mode of drug administration. In case of non-withdrawal of the medicines, this system is able to produce remote alarms.

The alarms and the presence data received from each sensor node are transmitted to a remote web server that allows a real time view of the elderlys mobility in the house and any potentially dangerous situation. Using the web server the presence data and alarms are immediately displayed on the Sibilla and on a Smartphone equipped with the dedicated application. In fact, the Sibilla smart lamp is programmed to continuously check the information stored in the web server and to display it. The same information could be viewed by dedicated smartphone or PC applications. The system also allows anyone who is registered and included in the list of contact numbers receive the alarm message in case of emergency.

The data exchange with the web server is allowed by the WiFi connection between the smart lamp and the home router. As shown in Fig. 3, the WiFi module integrated into MARCH'ingengo and Sibilla provides the communication between the two smart lamps and the home router. This WiFi module communicates with dedicated microprocessor via UART interface. The lamps were equipped with WiFi connectivity for not constrain their placement in proximity to a wired ADSL plug thus leaving the maximum freedom of positioning inside the dwelling.

The selected WiFi module manufactured by STMicroelectronics [5] is one of the least expensive on the market and is adequate for our needs to project a smart and inexpensive system. On this module we have implemented the WPS protocol to easily and securely connection to the domestic WiFi network . Pressing the WPS button on the domestic WiFi router it sends an 8 digits PIN code that is used for smart lamp module authentication by exchanging network name and keys set.

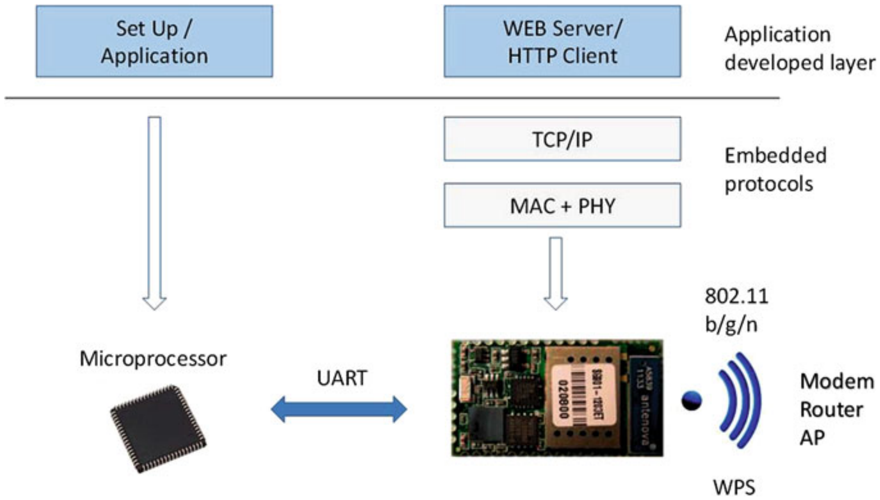

Fig. 3 Diagram of the link between the microprocessor of smart lamp and the home router via WiFi module

2.3 The Web Server

One of the most important features of the system is the capability for the authenticated remote user to manage the setting of the dispenser. It is allowed to define the conditions for opening each drawer with possible repetitions daily and duration of medicine treatment and with the inclusion of explanatory notes.

At the same time the information collected by the smart lamp MARCH'ingegno is transmitted to a remote web server via Internet to monitor the state of the elderly and his mobility inside the house. The system is developed exploiting the client-server architecture model. The client lies on MARCH'ingegno that is connected via the Internet to the mate lamp Sibilla, PC and smartphone. The diagram of the realized system is illustrated in Fig. 4.

The Microsoft Windows prototype server contains a socket based back end and a PHP based front end. The back end captures data received from the Internet, extracts the useful information and stores it into a database. The server needs to deal with many communication events because of the possible high number of clients. The server application consists of a listening socket, created at the starting of the task, and a client socket that are set up when a new client tries to connect to the server. The clients are grouped in three different types (MARCH'Ingegno, Sibilla, generic remote client and administrator) and every set can receive or transmit different types of data.

When a client calls the server, the listening socket will accept the call and a client socket is established. The front end provides services and database access, handling

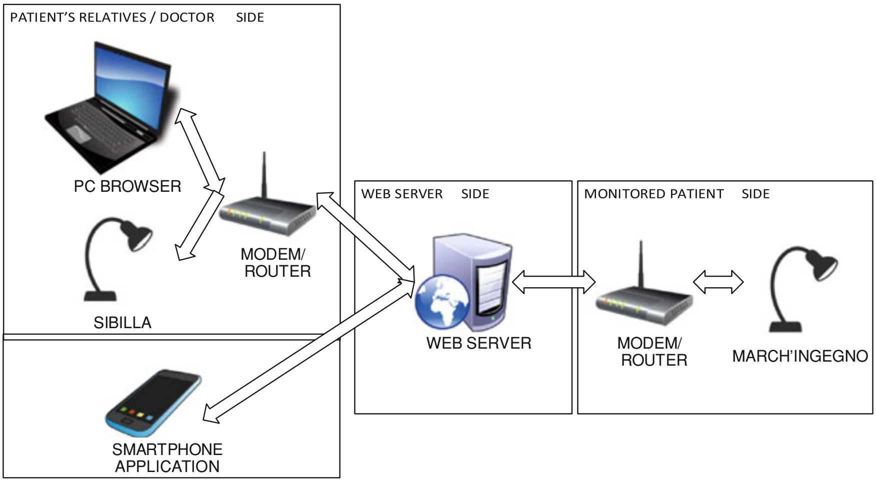

Fig. 4 Block diagram of the basic elements of the monitoring system

the data using PHP and MySql, displaying all the required information on the website, launching alarms or notifications, if necessary.

3 Conclusion

We have designed, by proposing a common object such as a LED lamp for smart lighting, an integrated multi-function system consisting of wireless sensor nodes. This WSN allows the remote setting and monitoring of a dispenser of medicines integrated into the lamp. It is also an environmental watching and alarm transmission resulting from the occurrence of abnormal events. In this way a design and everyday object becomes the main component of an AAL system integrating perfectly in a home environment without the need of invasive devices. Thanks to WiFi connectivity, RF interfaces and sensing capabilities MARCH'ingegno and Sibilla allow family members the continuous remote monitoring of the elderly, his mobility inside the house and his proper use of medicines.

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